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WATER WORKS RESERVOIRS

BY DABNEY H. MAURY

It is the purpose of this paper to describe briefly the several classes of water works reservoirs and explain their respective uses and limitations; to touch upon the value of the proper location of reservoirs, and especially of distributing reservoirs; to discuss the governing considerations in reservoir design; to describe some of the difficulties encountered in actual construction, and to give some suggestions, born of experience, which may help others to overcome these difficulties.

CLASSES OF RESERVOIRS

Broadly defined, a reservoir is a place in which something is kept in store. In water works reservoirs that which is stored is water.

An impounding reservoir is usually formed by building a dam across a stream, so that its waters may be conserved, especially at time of flood, for release during periods of drought. Such reservoirs may be used to store water for power purposes, or for irrigation, or to diminish the danger of damage from floods; but none of these uses would have any relation to water works. If, however, they store water for fire protection or domestic use, they may properly be classed as water works reservoirs.

Other water works reservoirs include what are known as suction reservoirs, storage basins, clear water reservoirs and distributing reservoirs. The first three of these are generally designed to store water which is pumped into them from wells or streams, or which flows into them from filters or settling basins.

Distributing reservoirs are connected to the water distributing system, usually in such a manner that the elevation of the water in the reservoir controls the pressure on the distributing mains. Such reservoirs are naturally built on high ground, and when they are made of steel in the form either of standpipes or of elevated tanks, their flow lines are frequently 100 feet or more above the surface of the ground on which they are located.

In any water works system there are usually a number of steps which lie between the taking of water from its original sources and the actual delivery of it to the consumer. These steps include some or all of the following:

(a) The collection and storage of the water of a stream in an impounding reservoir.

(b) The pumping of water from a stream or lake or from wells to a suction reservoir, or to a settling basin, or to filters, or directly into the distribution system.

(c) The purification of the water either by sedimentation, or by filtration, or by both.

(d) The pumping of the water from the surface reservoir, or from the sedimentation basin, or from the clear water reservoir of the filters, into the distribution system.

(e) The actual delivery of the water from the distribution system to the various consumers.

FIELD OF USEFULNESS

The usefulness of any reservoir depends upon, and is limited by, the position which it occupies in the order or procession of the steps just enumerated.

For example, if it be an impounding reservoir it can do no more than store the waters of the stream above it, and is of no value in conserving or helping out the capacity of the low lift pumps which take their supply from it; or of any suction reservoir, or filter plant, or clear water reservoir, which may follow it; or of the high lift pumps; or of the distribution system. If it be a suction reservoir or clear water well, then it will help out the capacity of everything back of it, which may be a stream, an impounding reservoir, wells, or low lift pumps taking water from any of these sources and delivering it into the reservoir under consideration, or a water purification plant which may discharge into it. Such a reservoir does not, of course, conserve the capacity of the high lift pumps which draw from it, or of the distribution system into which its waters are discharged.

A distributing reservoir, located on the discharge side of the pump and connected to the distribution mains, has more of these steps back of it than any of the other reservoirs just enumerated, and its usefulness may include the conservation of the capacity of stream,

or of impounding reservoir, or of wells, or of sedimentation basins, or of filter plant, or of low lift pumps, or of high lift pumps, or of all of these together.

A distributing reservoir properly located will, in addition to all of the foregoing, help out the capacity of the distribution mains themselves, and this last and very important function has in the past been frequently overlooked.

It follows from what has just been said that the nearer a reservoir is to the beginning of the order or procession of the successive steps in water supply, the less will be its value, other things being equal; and that the further along in this procession of steps, the greater will be the value of the reservoir.

VALUE OF PROPER LOCATION OF DISTRIBUTING RESERVOIRS

In order to derive the greatest possible benefit from a distributing reservoir, it should be properly located; and the intrinsic value of the proper location of such reservoirs has not always been appreciated in the design of water works systems. Where small water works plants have elevated storage, one frequently sees the tank located on the pumping station lot. A tank so located is in most cases a monument to the bad judgment of the man who designed the plant.

To illustrate the point, two cases, out of many that could be mentioned, will be cited:

In the first case the main pumping station was two miles north of the center of the congested value district in a small city. The elevated storage reservoir, originally built close to the pumping station, had been destroyed, and it was necessary to provide a new one.

For the purpose of computing the friction losses it was assumed that a fire broke out during sprinkling hours on a hot day in summer and that the plant would be required to furnish water at the rate of 4000 gallons per minute, distributed throughout the city for domestic consumption, in addition to a supply of 2000 gallons per minute for fire service, which latter amount would be drawn at or near the center of the congested value district. It was found that if the tower and tank were located close to the pumps at the northern end of the city the pressure remaining in the mains in the congested value district would be only 25 pounds, whereas with the same elevated tank

located near the southern end of the town the pressure remaining in the mains would be more than 53 pounds. To save this difference of 28 pounds by laying additional mains from the pumping station to the congested value district would have involved an expenditure of at least \$30,000; so that it may be fairly stated that the advantage obtained in this case by locating the elevated storage near the center of the congested value district instead of at the pumping station was worth not less than \$30,000.

In the second case, which involved a city of larger size than the one just mentioned, a site for an elevated reservoir of a capacity of 7,500,000 gallons had been selected on an eminence opposite the main pumping station. The congested-value district in this city was comparatively small, and its center was more than three miles south of the pumping station. A topographic map had been made of the proposed reservoir site, and test pits had been sunk through the top soil to bedrock, when the writer was called into pass upon the suitability of the topography and soil conditions for a reservoir of the capacity contemplated. It was at once apparent that the location of the reservoir with regard to the pumping station, to the distribution system of mains and to the territory to be supplied, was far from being a desirable one. An examination was made of high ground opposite the congested value district, with the result that a much more suitable site was discovered, which was later purchased by the city.

For the purpose of comparing the friction losses incident to the reservoir site originally chosen with those incident to the site recommended by the writer, it was assumed that the rate of domestic consumption during sprinkling hours on a hot day would be 3500 gallons per minute, which quantity of water would be distributed throughout the city, and that in addition to this 4000 gallons per minute would be required to meet the demands of a fire near the center of the congested value district.

The computations showed that had the reservoir been located opposite the pumping station the total friction losses would have been 96 feet, or about $41\frac{1}{2}$ pounds, whereas with the reservoir located near the center of the congested value district the friction loss under otherwise similar conditions would be only 3 pounds. The computations further showed that to reduce the friction loss to 3 pounds under the assumed conditions of demand, by putting in additional mains, would have cost more than \$200,000. The expenditure of so

large a sum of money would, of course, have been out of proportion to the benefits obtained, and the best economy would have dictated spending less money and putting up with somewhat greater friction losses. On the other hand, it would not have been economical to make the additional main smaller than 20 inches in diameter, had it been necessary to reduce the frictions by this method. The cost of even a 20 inch main would have been more than \$80,000. This sum is, therefore, considered to represent the lowest possible estimate of the advantage possessed by the site finally adopted for the reservoir over the one which had originally been chosen.

GOVERNING CONDITIONS IN RESERVOIR DESIGN

Among the first points to be determined are the location, capacity and elevation desired. These having been at least approximately determined, the work of designing may be begun.

The importance of proper location has already been discussed.

On the principle that one cannot have too much of a good thing, the capacity of the reservoir should be made as large as the finances of the local water department will permit. In any event, however, the reservoir should be made large enough to tide over the demand of the four or five hours of maximum consumption, and, if possible, its capacity should at least be equal to a full day's pumpage.

The elevation would be influenced by a number of conditions, the chief among which would be the topography of the city and the height and character of the buildings to be served. If pressure is increased during fires, it may often be found advisable to install an electric driven booster pump taking its water from the reservoir and pumping into the mains, the pump to be started when the fire alarm is turned in.

Generally speaking, where the elevation required is high and the capacity small, the reservoir will be an elevated tank supported by a tower, the whole structure usually being of steel. Other things being equal, that type of tank in which the average elevation of the stored water is highest is to be preferred; and when such tanks can be secured, as at present, at relatively low cost and in safe and attractive designs, it would seem that the old fashioned tall standpipe in which three-fourths of the contained water served no useful purpose except to support the remaining upper one-fourth, has no longer any right to exist. Where larger capacities are re-

quired, and where the flowline of the reservoir does not have to be far above the surface of the ground, the choice in most cases naturally falls on reinforced concrete as the material for the reservoir.

One point which frequently has to be decided is whether or not the reservoir shall be covered. One advantage of covering the reservoir is that the water is more easily protected against pollution, although it is usually possible so to fence and otherwise safeguard an open reservoir that the danger of pollution from the outside is almost negligible. Another minor advantage is that the roof will keep the temperature of the stored water more uniform, and prevent ice in winter and overheating in summer. Perhaps, however, the best service rendered by the roof would be the prevention of algae by the exclusion of the rays of the sun from the water. As it is possible at small expense and with the exercise of intelligent care to stop the growth of algae by the use of sulphate of copper, and as the addition of a roof almost always adds very greatly to the cost of a reservoir, most reservoirs, and especially those of large capacity, are of the open type.

The designer having reached this point can now proceed with the details. From now on he will probably work on the cut-and-try plan, making preliminary sketches and estimates of many different types of design, and abandoning one after the other until convinced that he has finally selected the best one, all things considered, for the local conditions. In a recent case more than a score of such trial computations were made on as many different types of reservoir wall before the wall which seemed to meet most satisfactorily all of the requirements was selected.

SOME TYPICAL DESIGNS

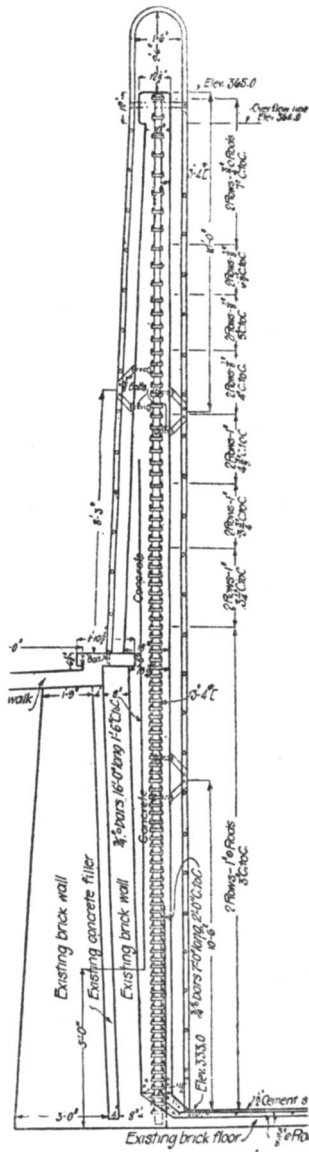
Figure 1 shows in cross-section the wall and part of the bottom of a 2,000,000 gallon reservoir, 120 feet inside diameter, 19 feet 10 inches deep at the wall, and 24 feet 10 inches deep at the center. This reservoir was built partly in excavation and partly in embankment on clay soil. Its bottom, which was five inches thick, was reinforced throughout with steel sufficient only to resist temperature stresses. The reinforcement in the wall was continuous around the circumference, and was designed to resist the internal pressures just as the hoops on a barrel resist the internal pressures in the barrel.

Figure 2 shows in cross-section the wall of another reservoir in which the steel reinforcement was stressed as are the hoops in a barrel. This wall was built to enlarge the capacity of an existing reservoir by increasing its depth from 14 to 32 feet. The inside diameter of the reservoir, as enlarged, was 142 feet, and its capacity about 4,000,000 gallons. Right along side of this old reservoir was constructed a new one which was so designed that the part of it which showed above the finished grade should be an exact duplicate of the enlarged old reservoir, and figure 3 is a section through the wall of the new reservoir. Here again the reinforcing steel is subjected to hoop stresses.

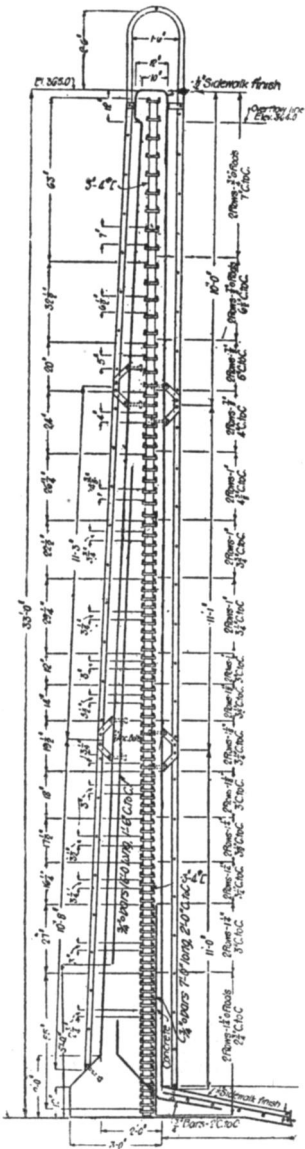
Criticising his own work in the light of later experience, the writer would say that in designing the wall shown in figure 3 he made a mistake in putting all of the steel near the inner face of the wall and none of it very close to the outer face. The practical result of this was that in the cold weather which followed shortly after the construction of this reservoir, vertical cracks showed up in the outer surface of the wall all the way around at distances of 20 or 25 feet apart. These cracks were visible only near the bottom where the wall was thickest and where the bulk of the concrete lay outside of the reinforcing steel. None of them went through the wall, and no leakage resulted from these cracks, so that they did no harm except to cause some unnecessary alarm when they were first discovered. They are not now in evidence, as the earth embankment around the reservoir covers the lower fourteen feet of its height.

Figure 4 is a section through the wall of a reservoir of 10,000,000 gallons capacity. The diameter of this reservoir is 300 feet, and its depth at the wall 15 feet, and at the centre 25 feet. The bottom is reinforced throughout to resist temperature stresses, and the wall is designed as a cantilever gravity section, with only enough steel around the circumference to resist temperature stresses. This reservoir is believed to be the largest reinforced concrete reservoir ever built without expansion joints. It was built in 100 days, and was practically watertight when finished.

Figure 5 is a plan, and figure 6 a section through the wall of a 7,500,000 gallon reservoir built almost wholly in excavation, a considerable portion of the excavation being stratified limestone rock. The diameter of this reservoir was 180 feet, and its depth 42 feet. In this case the lower part of the wall was thin and was built solidly against the rock, while that portion of the wall above the rock was



WALL SECTION
OLD RESERVOIR
FIG. 2



WALL SECTION
NEW RESERVOIR
FIG. 3

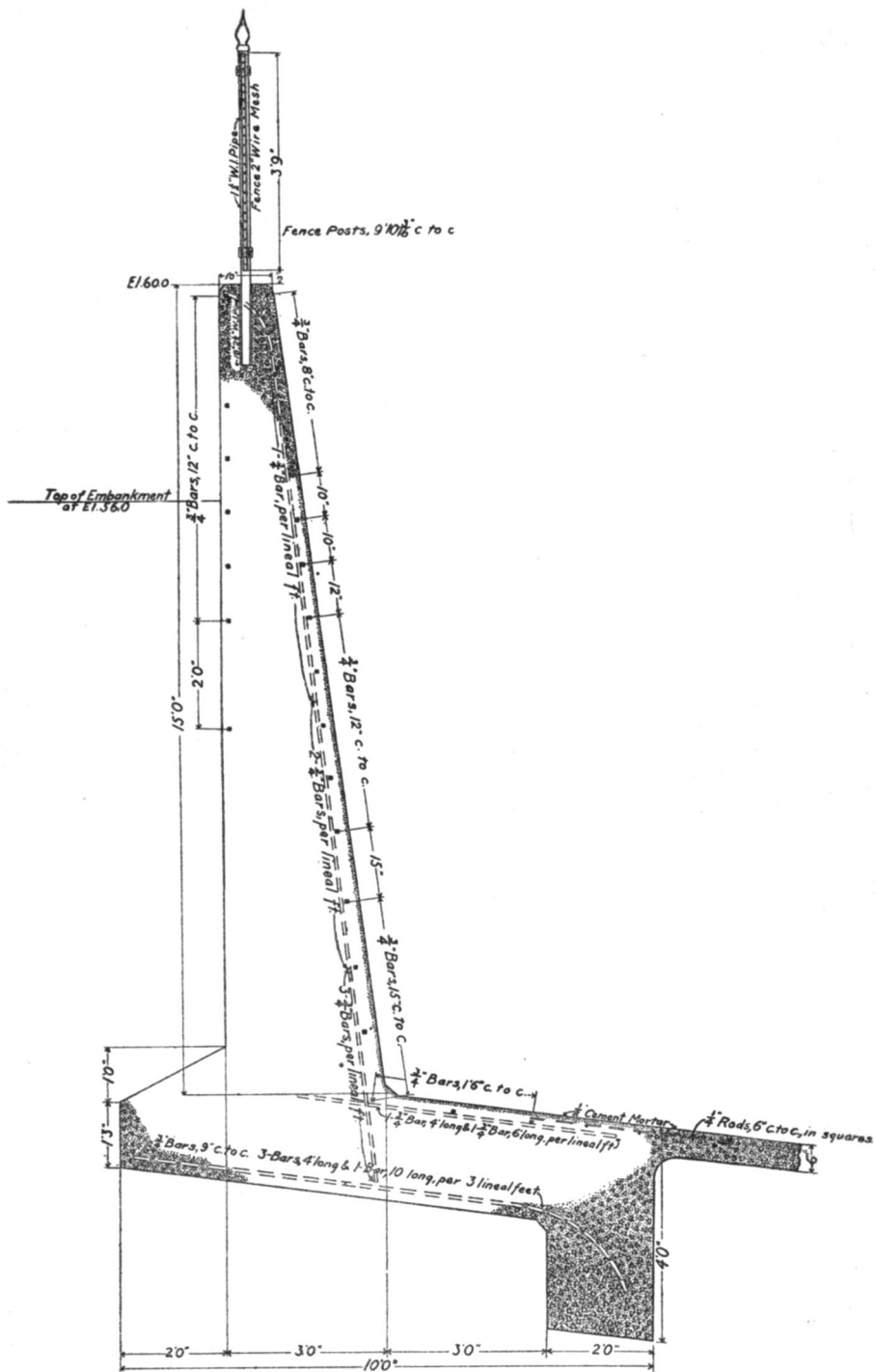


FIG. 4. WALL OF 10,000,000-GALLON RESERVOIR
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constructed as a continuous slab supported by buttresses carried down to the rock, the height of the thick portion of the wall and the height of the buttresses varying with the elevation of the upper surface of the solid rock.

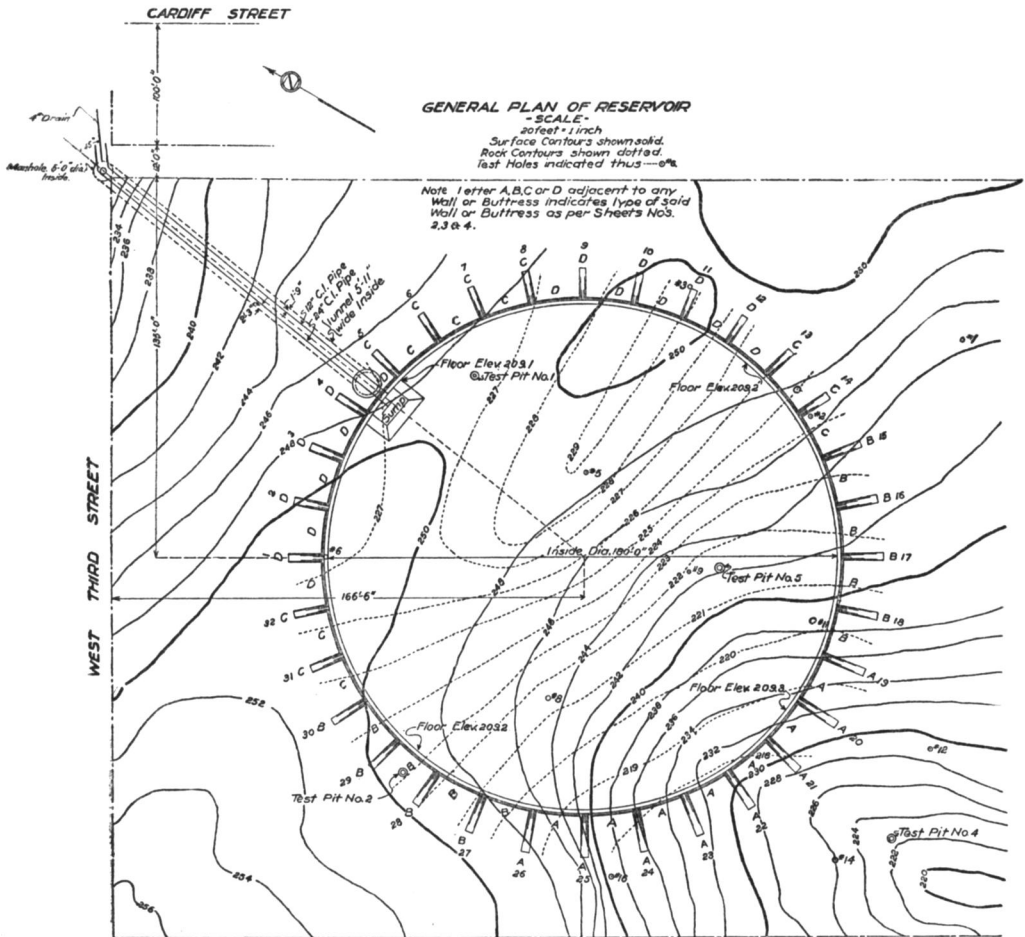


FIG. 5. PLAN OF 7,500,000-GALLON RESERVOIR

Figure 7 shows an entirely different type of reservoir, with beam and slab roof, slab walls and slab bottom for the bay next to the walls on each side, the remainder of the bottom being of the inverted groined arch type. This is not a distributing reservoir, but is in-

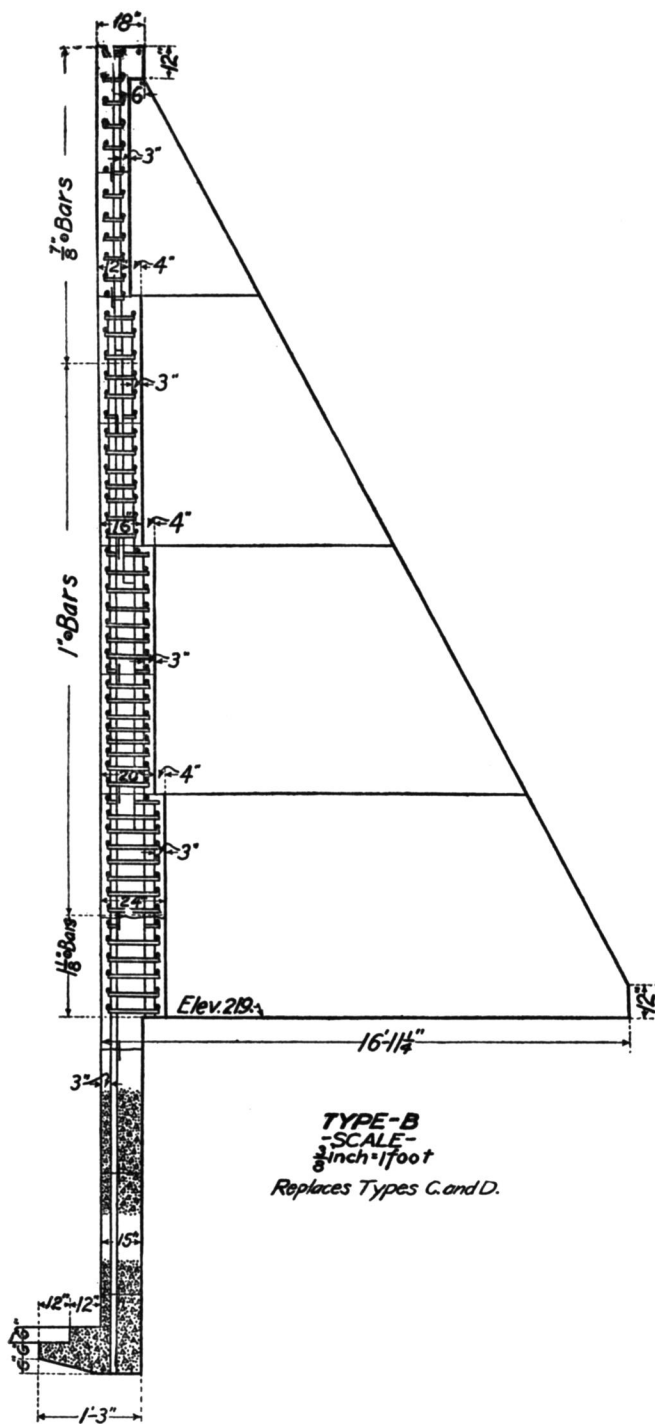


FIG. 6. WALL OF 7,500,000-GALLON RESERVOIR

tended to serve for the present as a storage reservoir for water pumped into it from distant wells. The reservoir is, however, so designed that later on its columns may serve as supports for an iron removal plant to be built on top of it, and it will then serve as a clear water reservoir. At times of very high water, the ground water, if it were unaffected by the pumping operations at the adjacent pumping station, would rise as high as the top of the reservoir, and if the reservoir were empty at such a time, the total upthrust would be greater than the weight of the reservoir and of its covering.

While it is not likely that there will ever be a time when the pumping operations at the station will cease for any long period, coincident with the pumping out of the reservoir itself, provision was nevertheless made to guard against any such contingency by sinking in each corner of the reservoir a 10 inch well equipped with a strainer of liberal area, having openings so large that they cannot become clogged by rust, and with a check valve opening into the reservoir. Should the ground water outside of the reservoir at any time rise higher than the water inside, these four wells will admit water to the reservoir with sufficient rapidity to prevent any danger from the unbalanced pressure of the ground water.

These wells were sunk before the construction of the reservoir was begun, and by pumping from them, the ground water, which would otherwise have stood several feet above the bottom of the reservoir, was held down below the bottom during the entire construction period, so that the whole structure was built in the dry.

A number of other reservoirs could be shown, but these six have been selected as representing more or less distinctive types. The wide variation in their design illustrates the effect of the local conditions and requirements in each particular case.

It will be noted that in the first three cases shown the reinforcing steel was stressed hoop-fashion, but that in the larger reservoirs of 10,000,000 and 7,500,000 gallons capacity, respectively, the hoop method was not used.

While no definite line can be drawn, it is thought that the 4,000,000 gallon reservoirs, which were 142 feet in diameter by 32 feet deep, were fairly close to the limit of size in which the hoop method of reinforcing could be economically employed. For capacities greater than these, the amount of steel required per vertical foot of wall becomes excessive, and usually some other type of wall will be found more economical for the larger reservoirs.

FIG. 7

Office of DABNEY H. MAURY
Consulting Engineer

Made by: G.A.W!

Checked by: FGG Subject:

Sketch Showing
RESERVOIR
Sioux Falls, S. D.

Date: June 29-1915.

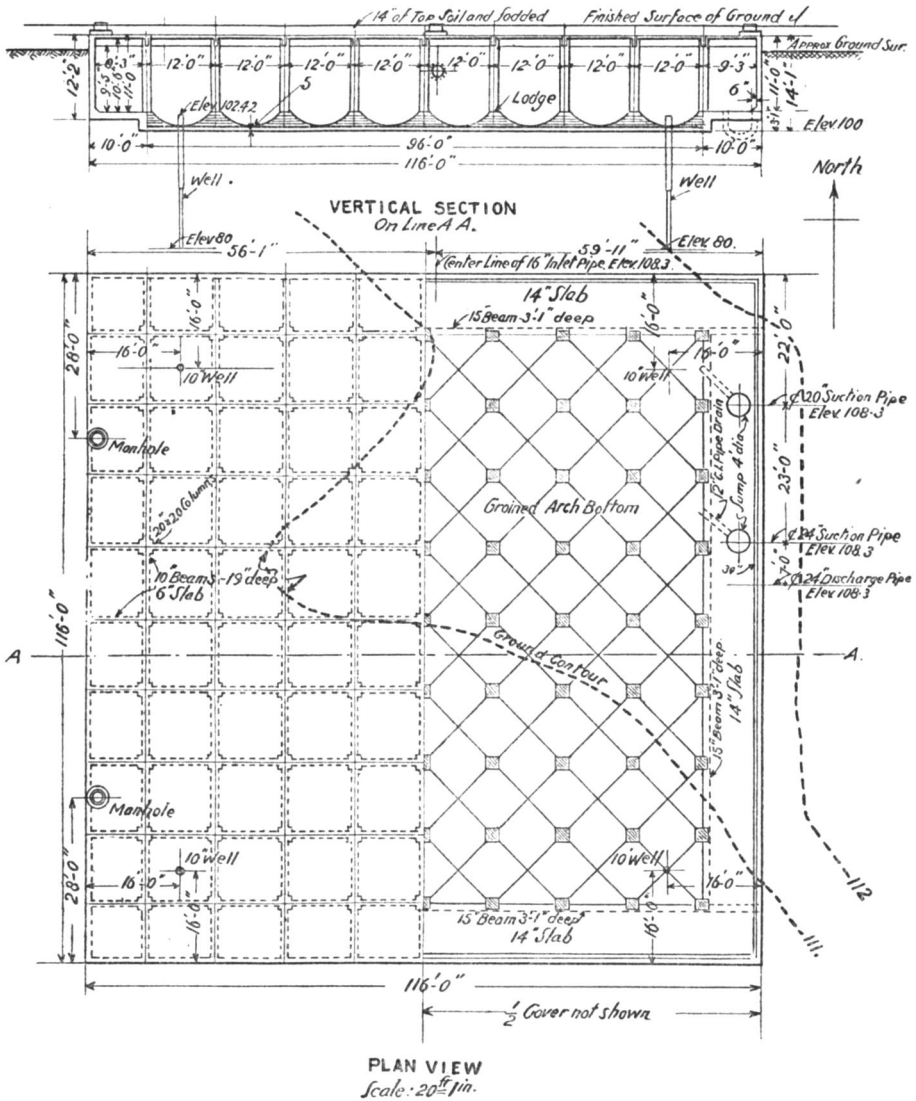


FIG. 7. PLAN AND SECTION OF 1,200,000-GALLON COVERED RESERVOIR

SOME CONSTRUCTION DIFFICULTIES AND SOME SUGGESTIONS

The first thing naturally demanded of a water works reservoir is that it shall hold water, and as a rule the most difficult part of the construction of a reservoir is making it watertight.

A small amount of leakage really does no great damage; but so long as any leakage can be detected, it is an eyesore, and it remains as a reproach to all of those in any way connected with the design or construction of the reservoir, whether contractor, engineer or owner. For these reasons, leaks so small that they could do not harm whatever are not as a rule permitted in the finished structure, even though the cost of stopping them is out of all proportion to the value of the water lost.

It was the writer's good fortune that in all of the reservoirs mentioned in this paper, he had to deal with contractors who endeavored honestly and conscientiously to secure good results. In almost every case they succeeded remarkably well, and when they failed, the failure was due to some oversight or bad judgment on their part, and not to any desire to skim the work.

It is not an easy matter to build a reservoir which shall be absolutely watertight from the time the forms are removed. Fortunately, however, very small leaks will usually become less or "take up" in a short time, especially when the stored water contains iron or sediment, and in most cases it is not very difficult to stop large leaks or at least to reduce them to so small an amount that they will ultimately stop of themselves.

Figure 8 is a construction photograph of the 2,000,000 gallon reservoir already mentioned, and shows the bottom completed and the vertical channels for supporting the reinforcing bars already in place, with over half of these bars fastened to the channels. These channels served another useful purpose in that they afforded a convenient means of fastening the forms without having to run bolts or wires all through the concrete.

Figure 9 shows this same reservoir after it was finished and while it was under its initial test. The white streaks are ice formed by the freezing of the water which leaked from the reservoir. It will be noted that there were practically no leaks except at the construction joints or horizontal planes between the successive pourings of the concrete. Because of the formation of ice the leaks appear very much larger in this photograph than they actually were, for the total

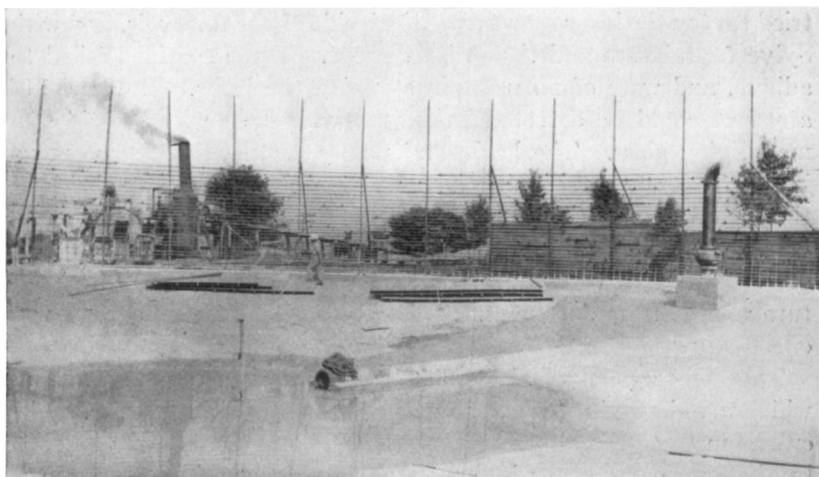


FIG. 8. 2,000,000-GALLON RESERVOIR DURING CONSTRUCTION

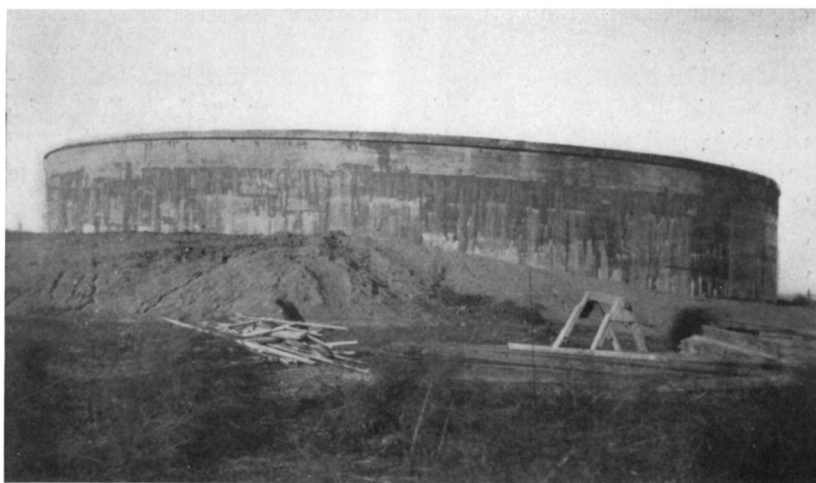


FIG. 9. 2,000,000-GALLON RESERVOIR AFTER FIRST TEST

leakage when the reservoir was first tested was not much over 3000 gallons per twenty-four hours. The contractor at first unwisely tried to stop the leaks by washing the inside of the reservoir, first with Sylvester mixture and then with cement. These coatings failed to adhere, and were of no value in stopping the leaks. No cracks of any sort could be detected in the reservoir even with the aid of a magnifying glass. The horizontal planes between successive pourings of concrete were plainly visible, and it was recommended that these be dug out in V-shaped grooves, running all around the reservoir, and having a depth of about $1\frac{1}{2}$ inches and a width of 1 inch at the surface, and that these grooves be carefully filled with a mixture of ironite and cement. This was done and the leakage was effectually stopped.

The construction of the 4,000,000 gallon reservoir, the wall of which was shown in figure 3, developed some surprising results. The enlargement to the old reservoir already shown in figure 2 was built by the same contractor who built the new reservoir shown in figure 3, the two jobs being parts of the same contract. The new reservoir was built first, and the enlargement to the old reservoir was made after the new reservoir had been put in service.

In this case, as in all of the others mentioned in this paper, the contractor was required to guarantee the watertightness of the finished work.

After the award of contract the writer discussed with the contractor the methods which he planned to employ in building the reservoir, and was informed that he intended to erect an elevator tower between the two reservoirs, construct the forms for the whole 32 feet in height of wall, and place his concrete in the wall by means of chutes, working day and night and pouring the concrete continuously until the entire wall was poured. The writer objected strongly to this method of construction, and spent much time in endeavoring to persuade him to abandon it, and to use removable forms not more than two or three feet in height, so that the concrete could be thoroughly spaded in place in the wall. Sketches of such forms were prepared, and estimates secured on steel forms which seemed to prove that they would be much cheaper than the wooden forms contemplated by the contractor. The contractor, however, argued that he had in stock a lot of lumber which could be used for forms and which he could so manipulate that it would suffer very little damage from such use. He further stated that he was afraid that

leaks would occur in the joints between successive pourings, and he claimed, with some justice, that so long as he was compelled to guarantee the final results, he was entitled to use any method of construction which he saw fit, provided the contract and specifications did not expressly forbid the use of that particular method. Finding himself unable to persuade or to compel the contractor to change his method of construction, the writer was obliged to allow the work to proceed.

In the meantime the contractor asked permission to use a cement with which the manufacturers mixed at the mill a certain alleged

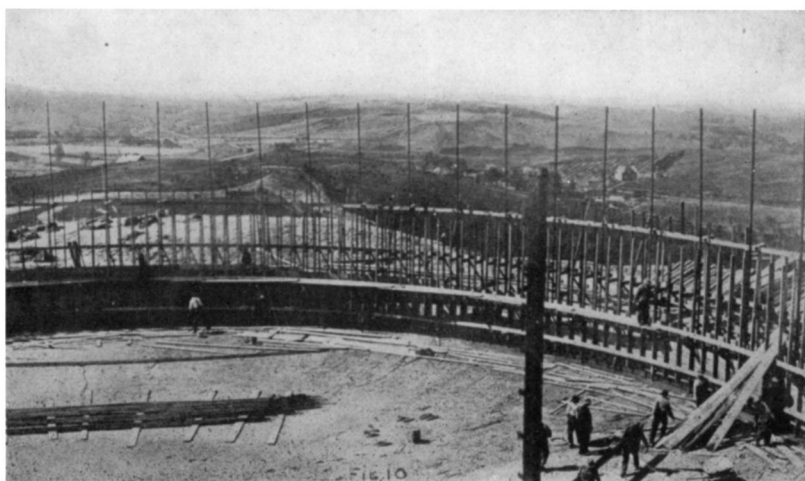


FIG. 10. ERECTION OF FORMS AND STEEL WORK, 4,000,000-GALLON RESERVOIR

waterproofing material. This cement, so mixed, was subjected to the usual laboratory tests by one of the city engineers who had charge of the supervision of the construction work on the ground, and passed successfully all of the tests applied, complying with all of the requirements of the standard specifications of the Society for Testing Materials. Permission was accordingly granted to use this brand of cement, subject always to the provisions of the contractor's guarantee of the final results.

Figure 10 shows the erection of the channels, forms and reinforcing steel for the wall in progress.

Figure 11 shows the reinforcement in the bottom of the reservoir.

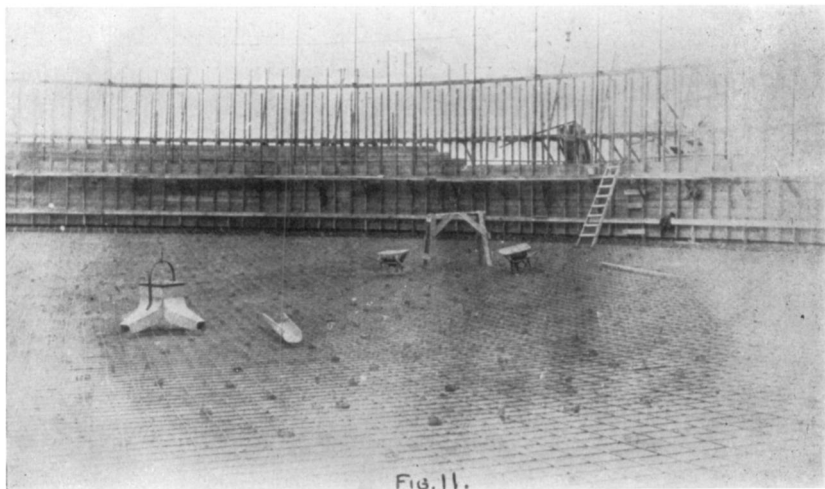


FIG. 11. CONSTRUCTION VIEW, 4,000,000-GALLON RESERVOIR, SHOWING REINFORCING STEEL IN FLOOR

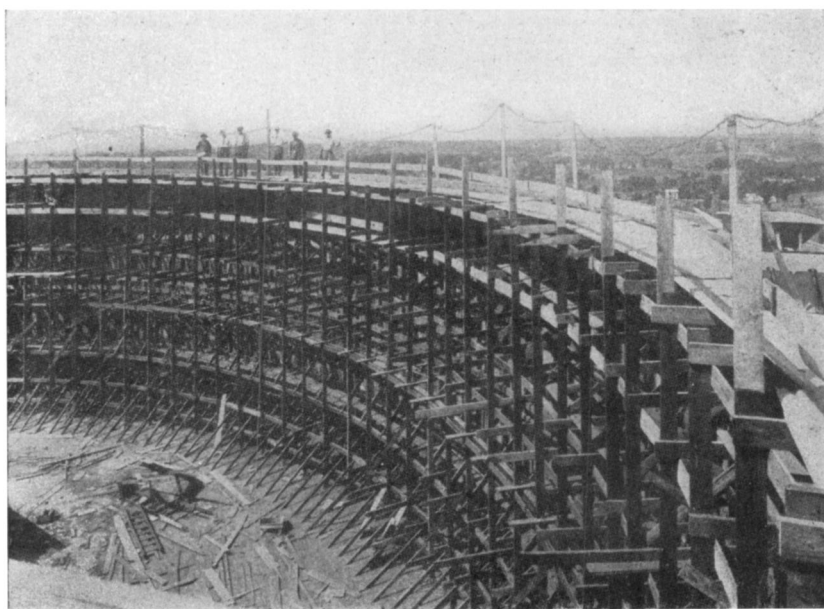


FIG. 12

Figure 12 shows the appearance of the structure after the reinforcing steel had all been placed in the wall, and the scaffolding for the wall forms had been practically completed.

Construction work proceeded rapidly, and it was evident that the contractor was doing all that could be expected of him to secure good results, but when the forms were removed, the entire surface of the wall was seen to be spotted with patches of a creamy or yellowish color. Investigation showed that wherever these patches occurred the material could be readily dug out of the wall with a pen knife, and this material contained no sand or stone, was almost as porous as a sponge or a piece of coral, and was so light that a

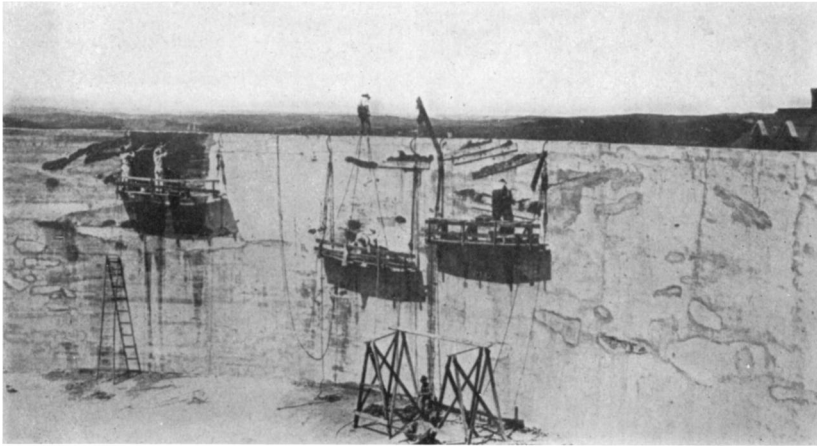


FIG. 13. CUTTING OUT SOFT SPOTS IN 4,000,000-GALLON RESERVOIR

lump of it would float in water. It was then evident that the so-called waterproofing mixture was of a soapy nature, and that when the concrete was poured down the chutes to its place in the wall, this soap formed a lather which separated from the stone and sand and from most of the cement, and lay on top of the rest of the ingredients. Just enough of cement appeared to remain in this lather to cause it to take a set.

Figure 13 shows the inside of the wall after the forms were removed, with some of the contractor's men cutting out the soft material and endeavoring to replace it with real concrete.

Figure 14 is another view of the same work. There were hundreds of these soft spots, most of which extended entirely through the wall,

the largest being about 25 feet long, by 3 or 4 feet deep. The contractor did his best to dig them all out and put good concrete in place of them, but as might be expected, the reservoir still leaked



FIG. 14. CUTTING OUT SOFT SPOTS AND PATCHING 4,000,000-GALLON RESERVOIR

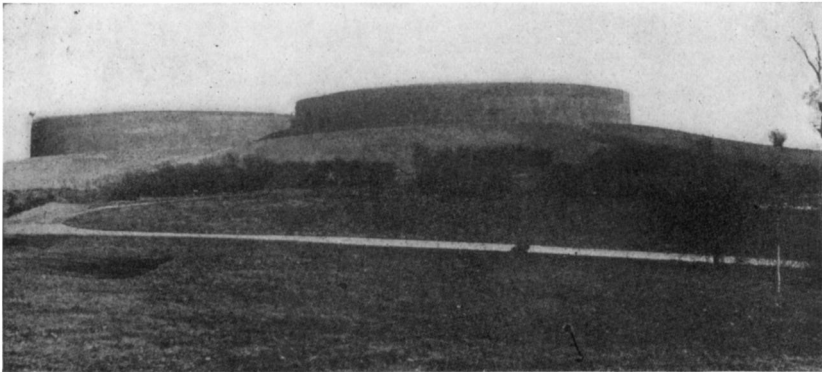


FIG. 15. THE COMPLETED RESERVOIR

after this had been done. When all of the soft spots had been dug out, and before the holes had been refilled with concrete, the structure resembled a gigantic bird cage as much as it did a reservoir; and it would have served almost as well for the one as for the other.

It was finally necessary to put in a membrane lining of waterproofing material over the wall and bottom, and to cover this with a protecting coat of several inches of reinforced concrete. This produced a watertight reservoir.

In the construction of the enlargement to the old reservoir, it is needless to say that the contractor did not pour all of the wall at one pouring, and that he did not use the so-called waterproofing substance. When the forms were removed from the second piece of work there were a very few small leaks which either stopped themselves in a short time, or were stopped without much difficulty.

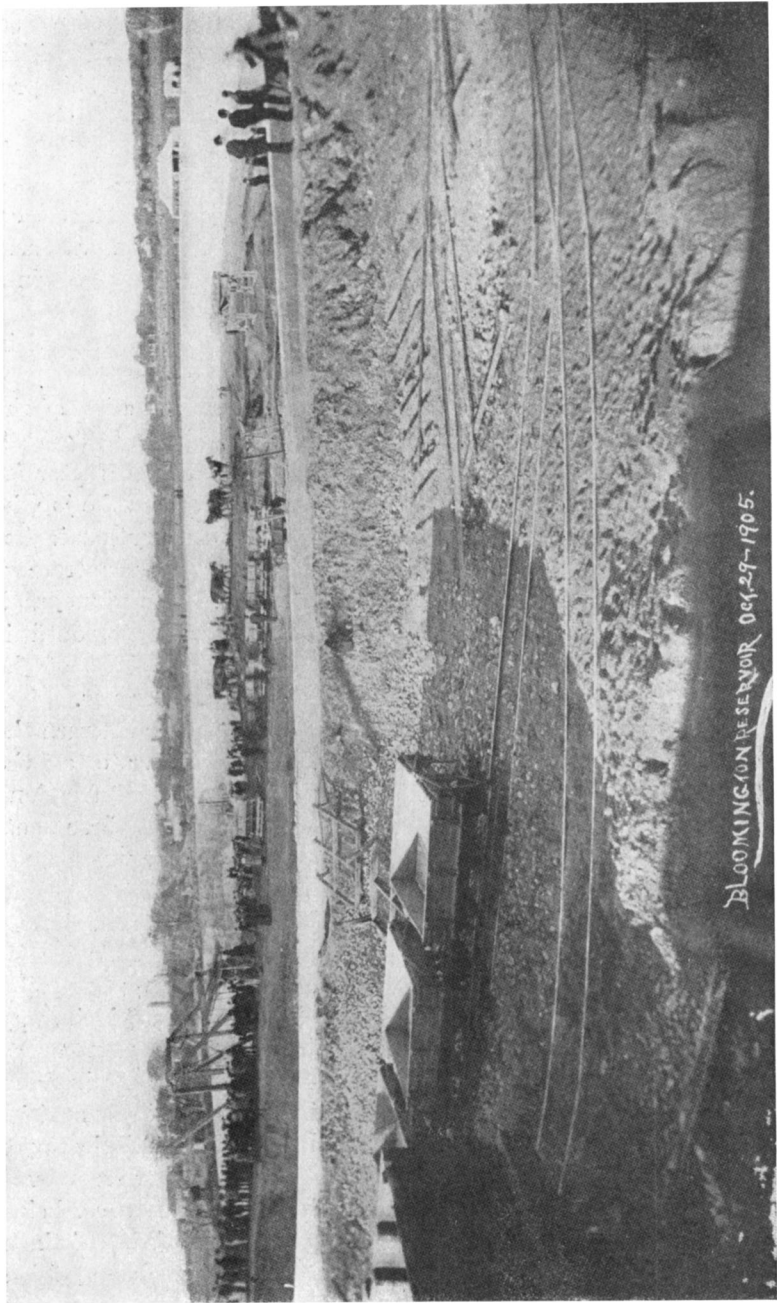
Figure 15 shows the two reservoirs as finally completed and in service.

Figure 16 is a photograph taken during the construction of the 10,000,000 gallon reservoir, the wall of which was shown in figure 4.

Notwithstanding the fact that the price which the contractor for this reservoir received yielded him no profit whatever on the job, he spared no expense to make his work first class in every particular, and he succeeded in this respect better perhaps than the contractors for any of the other reservoirs herein described. The photograph shows the wall of the reservoir completed, while the grading outfit is still engaged in removing the dirt from the center. Most of the excavation was done with a Page bucket, or dragline scraper.

After the forms were removed from the wall the space between the embankment and its outer surface was filled with water to test the wall for leakage. The inner surface of this wall was 942 feet long by 15 feet high, and in this entire area there were but three spots which showed any dampness. From one of these there was a small trickle amounting to only a few drops per minute.

There were no spots on the entire inner surface where stone showed against the forms, and this result was largely due to a device for which the contractor should be given credit. In building the wall a portable plate of thin metal was held at all times about $\frac{3}{4}$ inch away from the inner form, and as each batch of concrete was poured behind this plate, one-to-one cement mortar was poured in front of the plate and between it and the inside form, in quantities sufficient to keep the upper surface of the mortar level with the upper surface of the last batch of concrete. These plates were moved ahead as the pouring progressed around the circumference, being from time to time drawn up so that the mortar in front of them could unite thoroughly with the concrete behind them before either



BLOOMINGTON RESERVOIR DEC. 29-1905.

Fig. 16

had time to begin to set. The excellent results obtained in this work were due in part to this device of the contractor, and in part to the conscientious thoroughness which characterized all the rest of his work.

Figure 17 shows the excavation for the 7,500,000 gallon reservoir, the design of which was shown by figures 5 and 6.

Figure 18 shows the placing of the supports for the reinforcing steel.

Figure 19 shows the reservoir about half completed, and figure 20 is a view of the completed reservoir and gate house, taken before the



FIG. 17. EXCAVATION, SHOWING CLAY ABOVE AND STRATIFIED ROCK BELOW

grading had been finished and before the ornamental fence designed to protect the reservoir against pollution had been erected.

When this reservoir was finished and tested by filling the space between the outside of its wall and the surrounding earth with water, a number of spots showed on the inside, and there were two or three small streams which spurted out from the inner surface of the wall. When the reservoir was filled and the loss of water measured with a gauge, it was found that this amounted to about 32,000 gallons in twenty four hours, of which a very small part was due to evaporation. The wall of this reservoir was poured in 4 foot layers, and steel dams 8 inches high and $\frac{1}{8}$ inch thick were provided at each construction joint for the purpose of minimizing the tendency to

leakage at these joints. Incidentally, these dams, which were bolted to the vertical channels, assisted materially in the erection of the channels. There was only one leak of any size at a construction joint, and at this spot the surface of the joint had been covered by a

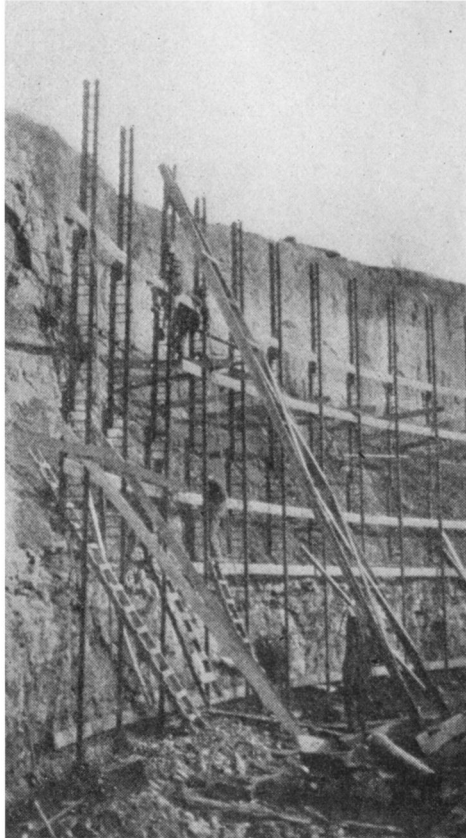


FIG. 18. PLACING SUPPORTS FOR REINFORCING STEEL

fall of clay from the bank above, and the contractor had evidently failed to remove all of this clay.

The specifications for this reservoir, as well as those for other more recent ones, called for the use of a vacuum cleaner for cleaning the surface of concrete already poured before fresh concrete should be poured on top of it. The work was not, however, supervised by the

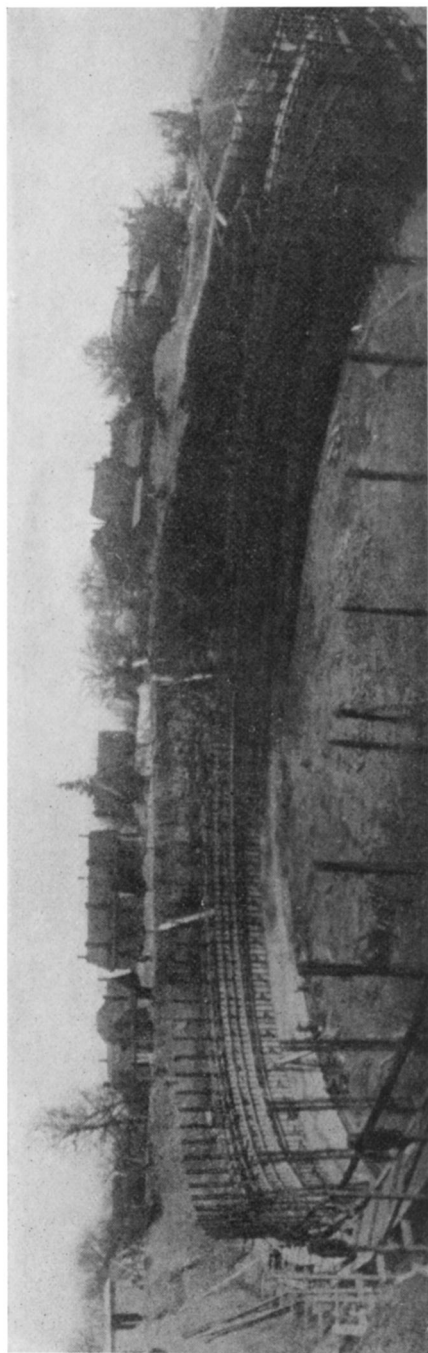


FIG. 19. RESERVOIR HALF COMPLETED

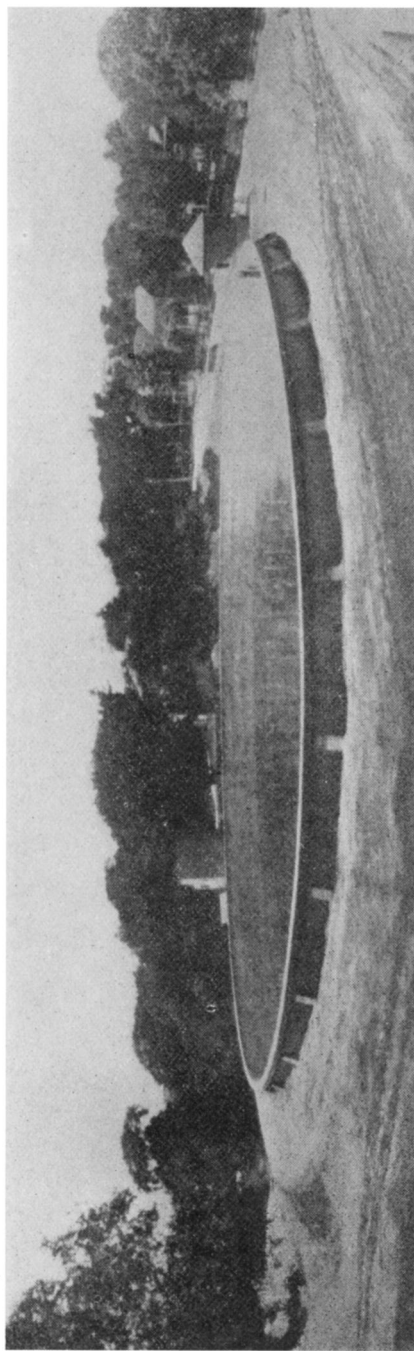


FIG. 20. 7,500,000-GALLON RESERVOIR COMPLETE, EXCEPT FOR GRADING, TURFING AND FENCING

writer, and this provision was not carried out, the contractor simply brushing the joints in the usual manner before pouring the next



FIG. 21. CONSTRUCTION VIEW, COVERED RESERVOIR

batch of concrete. This brushing of the joints cannot give the best results for the reason that the dust and rubbish and laitance are

simply moved from one part of the surface to another, whereas if a vacuum cleaner were used they could be removed entirely.

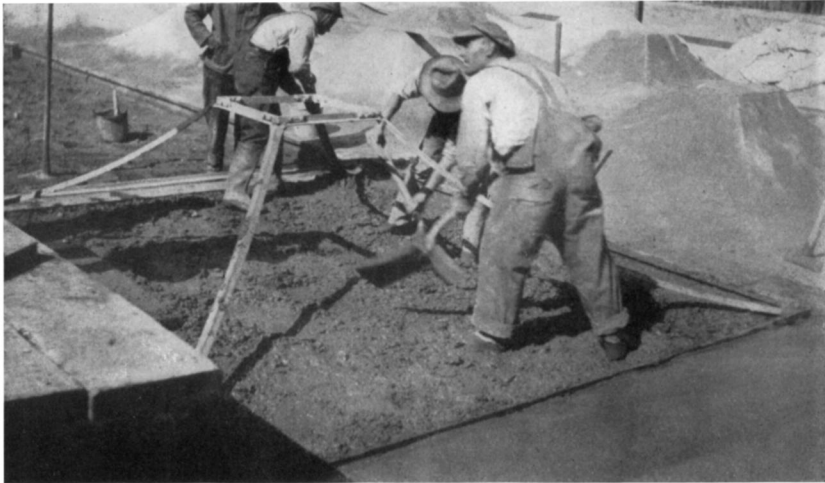


FIG. 22. PORTABLE STEEL FRAME FOR MOLDING GROUND ARCHES

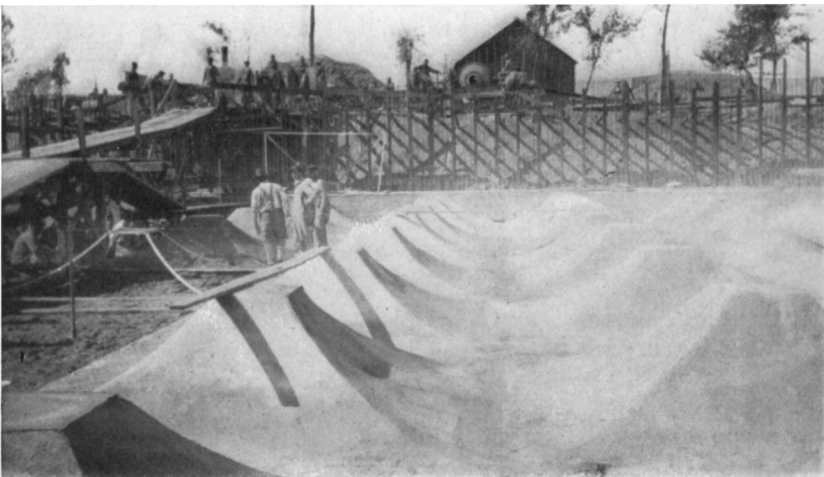


FIG. 23. PORTABLE STEEL FRAME AND SOME COMPLETED ARCHES

Figure 21 is a construction photograph of the 1,200,000 gallon covered reservoir already shown by figure 7. Attention is called to

the unusually careful and accurate manner in which the contractor for this work placed his reinforcing steel, the correct alignment of which shows very plainly in the photograph. This contractor also devised and used with great success a steel frame or templet for building the groined arches. These frames were so light that they could readily be moved from place to place, and the foundations for each column, instead of being built in four pieces, as is usually the case in this type of construction, were built in one piece, the concrete being simply piled up and tamped inside of the frame and smoothed off with a screen which was passed along the upper surface of the corner angles of the frame. The groins were then given a trowel finish. One of these frames is shown in figure 22, and another in figure 23, which also shows a number of the completed groined arches.

Figure 24 is an interior view looking down one bay of the completed reservoir, and showing the columns with the groined arches at the bottom, and the beam and slab roof at the top.

The workmanship on this reservoir was unusually good, the only defects being a few rough spots, which were promptly corrected by the contractor.

As a result of his experience with these and with a number of other concrete reservoirs, the writer would draw the following conclusions:

1. It is entirely possible with proper materials, mixture and workmanship to prevent moisture from passing through a concrete wall a foot thick even under fairly heavy pressures.
2. It is not to be expected, however, that the perfection of workmanship required to produce these results will always be obtained at every single point over an area of thousands of square feet of wall.
3. Such leaks as may show in spite of conscientious efforts to do good work can almost invariably be stopped entirely or be reduced to such a point that they will stop themselves in the course of time, especially if the water carries iron or sediment.
4. Leaks are most likely to occur at construction joints. The use of steel dams will reduce the danger of such leaks, but these dams cannot always be relied upon to prevent the leakage, and their presence should not be allowed to diminish in any way the precautions which should always be taken to prevent leakage at the joints.
5. The surface of concrete which has begun to set should be scratched and roughened, and all dust, rubbish and laitance should be carefully removed with a vacuum cleaner before the next batch of

concrete is poured. This will not always prevent leakage, but it will go far towards doing so.



FIG. 24. INTERIOR VIEW OF COVERED RESERVOIR

6. In reservoir construction the use of chutes for conveying concrete to its place in the wall should not be permitted unless the con-

crete is thoroughly remixed just before it reaches its final place in the wall.

7. While good results can be obtained by very careful spading of the concrete adjacent to the forms, so as to keep the stone away from the inner surface of the wall, it is believed that far better results would be secured by the plan devised by the contractor for the 10,000,000 gallon reservoir already described; namely, the use of a portable sheet of thin metal with means for holding it about $\frac{3}{4}$ inch away from the inner form, the concrete to be poured back of this sheet of metal, and cement mortar in front of it and between it and the form.